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TOTAL PHOSPHORUS BUDGET FOR LAKE ST. CLAIR: 1975-80

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ABSTRACT. As part of the U.S.-Canadian Upper Great Lakes Connecting Channels Study a total phosphorus budget was developed for Lake St. Clair. An unbiased ratio estimator technique was used to estimate annual loads and variances from monitored hydrologic areas. During the 1975-80 period, Lake Huron was the major source of phosphorus to Lake St. Clair, accounting for approximately 52% of the total annual load. Hydrologic area loads, which include diffuse and indirect point sources, contributed approximately 43% of the total annual load. The remaining 5% came from the atmosphere, shoreline erosion, and direct point sources. Of the hydrologic area loads, 85% could be attributed to diffuse sources. The Thames area contributed 58% of the total hydrologic area load, followed by the Sydenham (17%), the Clinton (9%), the Ruscom (7%), the Black (6%), the St. Clair (3%), and the Rouge (0.4%). Over the entire 6-year period examined, the lake's total input and output of phosphorus were nearly equal. It was concluded that there was no significant net source or sink of phosphorus in Lake St. Clair during the 1975-80 period.
ADDITIONAL INDEX WORDS: Water pollution sources, mathematical modeling, eutrophication, nutrients.

INTRODUCTION

Phosphorus budget calculations for the Great Lakes have generally overlooked the dynamics of phosphorus transport into and through Lake St. Clair. The sum of Lake St. Clair's point and non-point inputs has simply been included as part of the total load to the western basin of Lake Erie; the assumption has been that the entire input of phosphorus to Lake St. Clair is transported, unaltered, through the lake and into the Detroit River. Recent attention to the connecting channels of the upper Great Lakes, however, has served as the impetus for calculating a phosphorus mass balance for Lake St. Clair. The intent of this study was two-fold: 1) to estimate the total phosphorus budget for Lake St. Clair for the period 1975-80, and 2) to determine whether or not the lake is a net source or sink for phosphorus.

Lake St. Clair is unique against the pelagic backdrop of the Great Lakes because it is shallow (average depth = 3.3 m) and has a very short average hydraulic retention time (9 days). Lake St. Clair has a surface area of about 1,100 km^2 and a drainage area of about 15,500 km^2. We calculated the annual phosphorus loads entering this shallow, quick flushing lake from a variety of sources and compared them to the amount of phosphorus leaving the lake through the Detroit River. From these comparisons along with estimates of data and load uncertainty, we were able to draw certain conclusions concerning the likelihood of net sources or sinks of phosphorus in Lake St. Clair. Finally, the nature and estimated magnitude of possible sources and sinks of phosphorus are discussed.

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METHODS

The total phosphorus budget for Lake St. Clair includes external loads, internal sources/sinks, outflow losses, and changes in mass storage. At steady state, the sum of the external loads and internal sources/sinks should balance the outflow losses. External phosphorus loads to Lake St. Clair come from Lake Huron, shoreline and streambank erosion, atmospheric sources, direct point sources, and hydrologic area loads. Internal sources and sinks include particle settling and resuspension, groundwater input, bioturbation, and aquatic macrophyte uptake and release. The outflow loss is through the Detroit River.

External Loading Estimates

Lake Huron phosphorus loads were taken directly from Yaksich *et al.* (1982). They estimated the average daily loading at the head of the St. Clair River by multiplying the flow weighted mean yearly phosphorus concentration by the reported average daily flow per month. This daily load was adjusted by the number of days in the month to yield a monthly load. Loading from shoreline erosion was estimated by multiplying the length of Lake St. Clair shoreline by the annual loading rate of phosphorus per kilometer of shoreline for the Lake St. Clair basin (Monteith and Sonzogni 1976). Loading from streambank erosion (along the St. Clair River) was assumed to be negligible because the total loading to the Great Lakes from streambank erosion is < 4% of that contributed by shoreline erosion on the U.S. side of the Great Lakes (Knap and Mildner 1978).

Direct atmospheric loading was estimated to be the average (14.0 MT/yr) of values obtained during the field seasons of 1975 (Delumyea and Petel 1977, measurements made at stations around Southern Lake Huron) and 1981 (Klappenbach 1984, measurements made at Mt. Clemens, Michigan). Direct and indirect point source load estimates were compiled from the International Joint Commission (1982), the Great Lakes Basin Commission (unpub. data), and the Ontario Ministry of the Environment (1985).

Hydrologic Area Loads

Seven hydrologic areas were defined using the convention of Hall *et al.* (1976): the Black, St. Clair Complex, Clinton, and Rouge Complex (does not include the Rouge River) areas in Michigan, and the Ruscom, Thames, and Sydenham areas in Ontario (Fig. 1). Hydrologic area loads include diffuse loading from land areas that drain into a tributary or directly into Lake St. Clair, and indirect point source inputs. Indirect point source loads are those which discharge upstream of a river monitoring station. Their entire load was assumed to be transported to Lake St. Clair. Direct point sources were defined as those which discharge downstream of a river monitoring station or directly into the St. Clair River or Lake St. Clair. Inputs from these sources were not included as

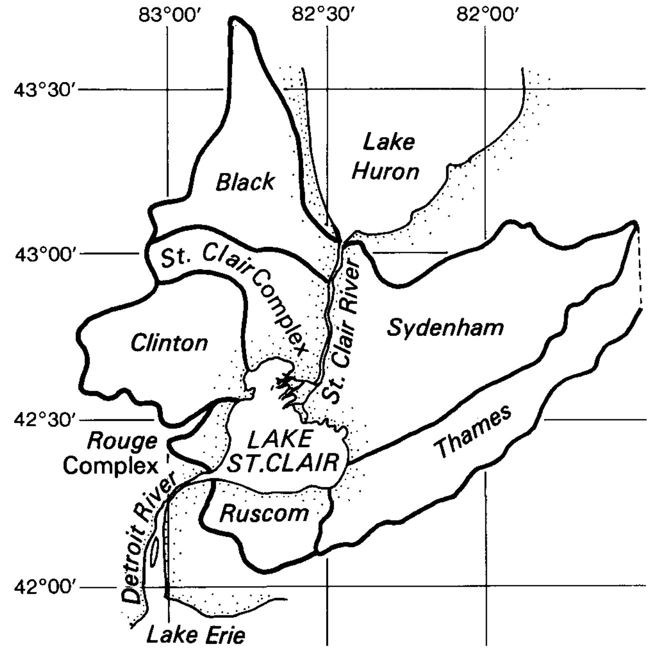

FIG. 1. Lake St. Clair basin showing hydrologic areas used in calculating load estimates. Note: the Thames hydrologic area extends to approximately 43° 30′ latitude, 80° 30′ longitude.

part of the hydrologic area loads. Several small (< 1 MGD) point source discharges may have been omitted from our hydrologic area analysis since scant information existed for them during 1975–80. However, analysis of recent municipal point source data from STORET (USEPA) and industrial point source data from the Ontario Ministry of the Environment (1985) shows that these sources presently represent about 1% of all of the point source flows. Therefore, their omission should have little or no effect on calculation of loads from hydrologic areas.

Each hydrologic area load equaled the sum of its monitored and unmonitored area loads (see below). The total annual hydrologic area load to the lake equaled the sum of the annual loads from the seven individual hydrologic areas.

Monitored areas. The portion of the hydrologic area load from monitored tributaries was calculated using the unbiased stratified ratio estimator method as described in Sonzogni *et al.* (1978). This method was developed by Beale (1962) and was evaluated by Dolan *et al.* (1981) as the most suitable for application in the Great Lakes basins. Tributary concentration and flow data were used to estimate the average daily load at the mouth, adjusted to minimize the variance associated with the flow component, as follows:

$$U_y = U_x \cdot \frac{M_y}{M_x} \cdot \frac{\left(1 + \dfrac{S_{xy}}{nM_yM_x}\right)}{\left(1 + \dfrac{S_x^2}{nM_x^2}\right)} \qquad (1)$$

where U_y is the unbiased estimate of the daily load at the mouth, U_x is the mean daily flow for the year, M_y is the mean daily loading for the days for which concentration data exists, M_x is the mean daily flow for the days for which concentration data exists, n is the number of days for which concentration data exists, and

$$S_{xy} = \frac{\sum_{i=1}^{n} X_iY_i - nM_yM_x}{n-1} \qquad (2)$$

$$S_x^2 = \frac{\sum_{i=1}^{n} X_i^2 - nM_x^2}{n-1}, \qquad (3)$$

where X_i is the individual measured flow for each day for which concentration data exist and Y_i is the loading for each day for which concentration data exist (calculated as the product of the individual measured flow and the total phosphorus concentration). Since the calculated load U_y includes any indirect point sources, the diffuse component of the monitored tributary load was estimated by subtracting the indirect point source inputs from the total calculated load.

The estimated mean square error of the estimated load (the square root of which is the estimated standard error of the mean) was also calculated using the ratio estimator method,

$$E = M_y^2 \cdot \left[\frac{1}{n} \cdot \left(\frac{S_x^2}{M_x^2} + \frac{S_y^2}{M_y^2} - 2\frac{S_{xy}}{M_xM_y}\right) \qquad (4)\right.$$

$$\left. + \frac{1}{n^2} \cdot \left(2 \cdot \left(\frac{S_x^2}{M_x^2}\right)^2 - 4\frac{S_x^2}{M_x^2}\frac{S_{xy}}{M_xM_y} + \left(\frac{S_{xy}}{M_xM_y}\right)^2 + \frac{S_x^2}{M_x^2}\frac{S_y^2}{M_y^2}\right)\right]$$

where E is the estimated mean square error of the load estimator and S_y^2 is calculated analogously to S_x^2. In an attempt to quantify some of the uncertainty of these loads and to statistically compare the total annual external load with the outflow loss, the root mean square error (RMSE) is used in a later section to estimate 90% confidence intervals around the individual tributary loads, the total external loads, and the outflow losses.

Three hydrologic areas (Clinton, Thames, Sydenham) were 100% monitored during the entire study period. Percent monitored represents the percent of the hydrologic area that is monitored. The Black area was not monitored for years 1975–77 and 100% monitored for years 1978-80. The St. Clair and Ruscom areas were 36% (Belle R.) and 18% (Ruscom R.) monitored, respectively, during the study period. The Rouge area was not monitored. On an areal basis, 83% of the Lake St. Clair basin was monitored during the study period.

Flow data were obtained from the U.S. Geological Survey (1976–82) and the Water Survey of Canada (1976–81). Flow measurements recorded at gaging stations located upstream of the river mouth were corrected to the river mouth by multiplying the gaged flow by the ratio of the entire drainage area to the gaged drainage area as described in Sonzogni *et al.* (1978). Phosphorus concentrations were obtained from the U.S. Environmental Protection Agency's STORET system, the U.S. Geological Survey (1976–82), and the Ontario Ministry of the Environment (1975-80). In most cases, water quality monitoring stations were located at or near the river mouth. It was assumed that these phosphorus concentrations equaled the concentrations at the mouth.

Unmonitored areas. Some hydrologic areas and individual tributaries were not sufficiently monitored (fewer than six samples per year) over some or all of the 1975–80 period. In addition, some land areas drain directly into Lake St. Clair or the St. Clair River, and therefore cannot be monitored. Diffuse loads for these watersheds were estimated as the product of the unmonitored area and a diffuse unit area load (UAL) from a monitored area with basin characteristics similar to the unmonitored area, as described in Sonzogni *et al.* (1978). The diffuse UAL is defined as the calculated diffuse load from a monitored area per unit area per unit time. The selection of a representative monitored area was based on soil texture, surface geology, runoff characteristics, land use, and proximity to the unmonitored area. Indirect point sources discharged in the unmonitored area were added to the estimated diffuse load to yield a total load for the unmonitored area. Because of the method used to estimate the loads from unmonitored areas, calculation of the RMSE associated with these loads was not possible.

Total External Load

The total external phosphorus load to Lake St. Clair equaled the sum of loads from hydrologic areas (monitored and unmonitored), atmospheric sources, shoreline erosion, direct point sources, and Lake Huron. The variance associated with the total external load was not known because some hydrologic areas were partially or totally unmonitored and variance estimates were not available for the atmospheric, erosion, direct point, or Lake Huron loads. However, an estimate of the variance associated with the total external load was made using the following procedure. Annual load probability distributions for each monitored tributary and the outflow from Lake Huron were constructed with means set equal to their estimated annual loads. The variances of the tributary load distributions were calculated from their estimated RMSE (eq. 5). The variance of the Lake Huron load distributions was assumed to be constant and equal to the variance of the Huron load averaged over the 6-year period. For each of the 6 years, values from each distribution were randomly selected and summed to give a single estimate the total annual external load (Fig. 2). This procedure was repeated 12 times to yield a combined probability distribution for each year's external load from monitored tributaries and Lake Huron. A sample size of 12 corresponds to the average number of times per year that each tributary was sampled. The standard error of the total annual external load was estimated from each year's combined probability distribution for the purpose of statistical comparison with the outflow data.

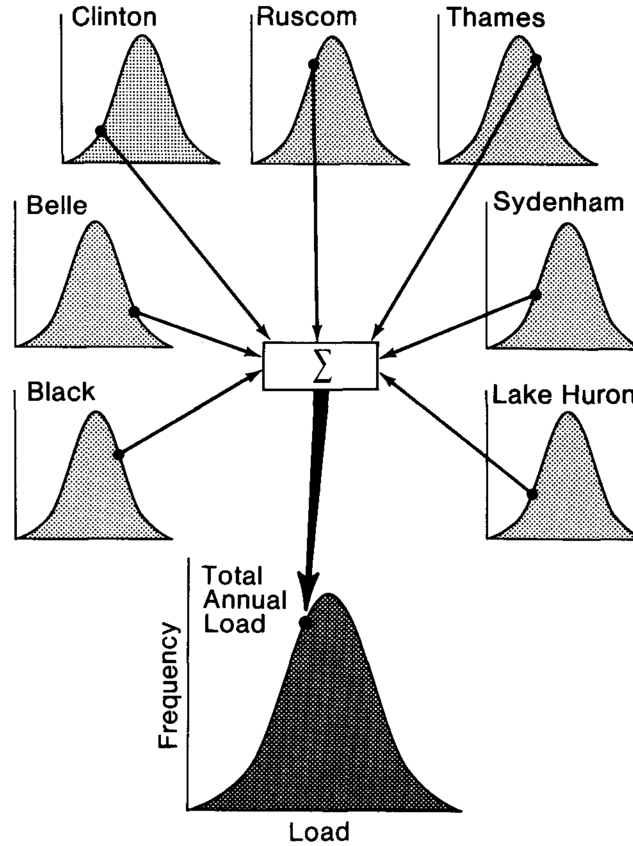

FIG. 2. Procedure used to construct the combined probability distribution for each year's external load from monitored tributaries and Lake Huron. The standard errors (S.E.) of the total annual external loads were estimated from these combined probability distributions.

Outflow Loss

Annual phosphorus losses through the Detroit River and the mean square error associated with these losses were estimated using the unbiased ratio estimator technique. Phosphorus concentrations were measured along a transect at Windmill Point near the head of the Detroit River by the Michigan Department of Natural Resources and recorded in EPA's STORET data base. There were ten stations along the transect, each representing 10% of the flow of the Detroit River. The data from these stations were limited to non-winter months (usually April through October). Phosphorus data for the winter months were measured at the Detroit municipal water treatment facility at Waterworks Park and recorded in the U.S. Geological Survey (1976–82). Water quantity data were taken from the results of a hydrodynamic model of the Detroit River (Quinn and Hagman 1977).

Internal Sources and Sinks

Scant quantitative information exists concerning the annual internal input or loss of phosphorus in Lake St. Clair. It is estimated that some sources and sinks vary seasonally (e.g., particle settling and resuspension and aquatic macrophyte uptake and release), while others remain more or less constant throughout the year (e.g., groundwater input and bioturbation). For the purpose of annual budget calculations, the total amount of phosphorus added to or lost from the lake via internal sources and sinks was estimated as the difference between annual external loads and annual outflow losses.

RESULTS

The estimated annual tributary phosphorus loads from monitored hydrologic areas to Lake St. Clair as well as the annual Detroit River outflow losses for 1975–80 are presented in Table 1. Table 1 also includes the estimated RMSE of the estimated loads and the 90% confidence intervals around the estimated loads. The RMSE and the Student's t-statistic were used to calculate the 90% confidence intervals (Remington and Schork 1985).

The total annual phosphorus budget for Lake St. Clair is presented in Table 2. On the average, Lake Huron contributed a major portion (about 52%) of the external total phosphorus load. The contribution of hydrologic areas was also significant and equaled approximately 43% of the external phosphorus load to Lake St. Clair. The remaining 5% of the total annual load came from the atmosphere (0.5%), shoreline erosion (2.6%), and direct point sources (1.9%). Expressed on a volumetric basis, the external total phosphorus loading to Lake St. Clair during the 1975–80 period was the largest in the Great Lakes (0.85 $g/m^3/yr$). Estimated volumetric loads to the western basin of Lake Erie during the mid-1970s (Chapra and Sonzogni 1979) were only half as large. However, the trophic state of Lake St. Clair does not necessarily reflect this high volumetric load because of the lake's extremely high flushing rate (average hydraulic retention time is only about 9 days). Average phosphorus dynamics of Lake St. Clair during the 1975–80 period are summarized in Figure 3. In the diagram, the relative proportion of inflows and outflows are approximated by the thickness of the arrow shafts.

Hydrologic area loads originating from Canadian sources averaged 82% of the total hydrologic area load to Lake St. Clair. The Thames and Sydenham areas contributed 92% of the total Canadian hydrologic area load. The Black and Clinton areas were responsible for 83% of the total U.S. hydrologic area load. The largest individual hydrologic area load originated from the Thames area. In all years except 1975, loading from the Thames exceeded 50% of the total hydrologic area load (the 6-year average contribution was 58%). The Thames area load was followed by the Sydenham (17%), the Clinton (9%), the Ruscom (7%), the Black (6%), the St. Clair (3%), and the Rouge (0.4%).

Over the 6-year period investigated, about 85% of the total hydrologic area load was calculated to originate from diffuse sources. The remaining 15% came from indirect point sources. The diffuse portion of the Thames and Sydenham area loads accounted for most of the total diffuse load (62% and 20%, respectively). The Clinton and Thames areas contributed a majority of the total indirect point source load (43% and 35%, respectively).

Internal Sources and Sinks

Assuming estimated loads presented in Table 2 are an accurate representation of the actual loads and assuming steady state conditions, then the difference between external loads and outflow losses is a measure of the internal sources/sinks of phosphorus in Lake St. Clair. The total annual incoming load falls within the 90% confidence interval around the Detroit River outflow loss for all years except 1976 (Fig. 4). The 6-year mean external load (3,133 MT/yr) and loss (3,148 MT/yr) were not found to be statistically different at the 10% level of significance (t-test; Remington and Schork 1985). The root mean square difference between annual external loads and outflow losses was only 7% of the mean external load (5% excluding 1976 values). Therefore, given the above assumptions and results, there appeared to be no net internal source or sink of total phosphorus in Lake St. Clair during 1975–80.

DISCUSSION

One objective of this study was to determine whether or not Lake St. Clair is a net source or sink for phosphorus. The total incoming load fell within the 90% confidence interval around the Detroit River loss for all years except 1976. Averaged over 6 years, external loads were not significantly different from outflow losses. These findings imply no net internal source or sink of phosphorus in the lake during 1975–80. However, because the net internal sources/sinks were calculated as the difference between the incoming loads and outflow losses, their validity is limited by the accuracy and precision of the load/loss estimates. If loads and losses are sufficiently accurate and precise then the conclusion that net internal

TABLE 1. 1975–80 annual river mouth loadings. The load is followed by the root mean square error, the 90% confidence interval in brackets, and the number of phosphorus samples. Units in MT/yr.

Monitored Tributary Name	Year					
	1975	1976	1977	1978	1979	1980
Black	N/A[1]	N/A[1]	N/A[1]	47.4	90.8	88.4
				2.9	38.9	29.0
				[41.9, 52.9]	[21.0, 160.6]	[34.5, 142.4]
				8	12	9
Belle[2]	31.1	28.7	7.1	10.4	11.9	17.4
	4.9	8.7	0.9	0.9	2.1	4.7
	[22.2, 40.0]	[13.1, 44.4]	[5.5, 8.6]	[8.8, 12.0]	[8.0, 15.7]	[8.7, 26.2]
	11	12	12	12	12	9
Clinton	198.4	143.8	118.3	112.7	77.8	114.0
	22.3	24.0	16.9	23.3	8.9	28.9
	[158.3, 238.4]	[100.8, 186.9]	[88.0, 148.7]	[70.9, 154.5]	[62.0, 93.7]	[62.2, 165.8]
	12	12	12	12	12	12
Ruscom	3.8	6.0	16.3	22.3	9.0	36.3
	0.1	0.5	1.3	6.0	1.8	20.7
	[3.7, 3.9]	[5.1, 6.9]	[14.0, 18.6]	[11.5, 33.1]	[5.7, 12.3]	[0.0, 75.4]
	7	11	11	12	12	8
Thames	418.3	690.8	1,391.8	643.3	917.7	663.8
	60.4	160.6	427.4	58.1	193.3	102.1
	[309.9, 526.8]	[396.5, 985.1]	[625.1, 2,158.4]	[537.9, 748.7]	[587.0, 1,248.4]	[493.8, 833.8]
	12	10	12	11	25	75
Sydenham	196.0	195.5	494.3	94.4	241.1	170.3
	28.6	46.9	137.1	18.6	27.1	19.2
	[142.9, 249.1]	[110.5, 280.5]	[248.4, 740.2]	[61.1, 127.8]	[195.0, 287.2]	[137.7, 202.9]
	9	12	12	12	27	31
Detroit	2,769.3	3,935.9	3,304.7	3,090.2	2,879.7	2,908.7
	289.7	301.5	393.4	250.3	247.9	273.3
	[2,244.2, 3,294.4]	[3,383.3, 4,488.6]	[2,603.6, 4,005.9]	[2,644.1, 3,536.2]	[2,448.5, 3,310.9]	[2,427.3, 3,390.1]
	11	10	13	13	18	15

[1]Phosphorus data not available for years 1975–77.
[2]Located within St. Clair hydrologic area.

sources/sinks were negligible during the study period seems reasonable.

It is difficult to determine how accurate the estimated loads and losses are since actual loads and losses can never be known exactly. Sonzogni *et al.* (1978) noted that the RMSE terms presented in Table 1 are useful for statistical comparisons, but they do not necessarily reflect how close the estimated load is to the true load. The RMSE is an estimate of the error determined from a limited number of daily samples, based on the premise that the true annual load can be determined by sampling flow and concentration at the river mouth each day of the year. In addition, the

TABLE 2. Annual phosphorus budget (MT/yr) for Lake St. Clair (1975–80). Values in parentheses represent percent of total load from diffuse sources. Percent monitored refers to percent of hydrologic area that is monitored.

Source	1975	1976	1977	1978	1979	1980
Hydrological Areas (HA)						
Black	115.5[a]	84.5[a]	41.9[a]	47.4	90.8	88.4
0,100% monitored[b]	(74)	(64)	(28)	(36)	(67)	(63)
St. Clair[c]	75.4	68.7	7.8	17.0	21.2	38.2
36% monitored	(90)	(89)	(3)	(56)	(64)	(80)
Clinton	198.4	143.8	118.3	112.7	77.8	114.0
100% monitored	(48)	(26)	(21)	(37)	(18)	(39)
Rouge[d]	10.8	4.2	2.9	4.7	1.6	5.0
0% monitored	(100)	(100)	(100)	(100)	(100)	(100)
Ruscom[e]	21.8	34.1	92.2	126.4	51.1	205.7
18% monitored	(100)	(100)	(100)	(100)	(100)	(100)
Thames	418.3	690.8	1,391.8	643.3	917.7	663.8
100% monitored	(85)	(90)	(94)	(91)	(92)	(90)
Sydenham	196.0	195.5	494.3	94.4	241.1	170.3
100% monitored	(97)	(97)	(99)	(92)	(99)	(99)
Total HA Load	1,036.2	1,221.7	2,149.2	1,045.9	1,401.3	1,285.4
	(80)	(82)	(90)	(83)	(87)	(86)
Atmospheric	14.0	14.0	14.0	14.0	14.0	14.0
Erosion	82.5	82.5	82.5	82.5	82.5	82.5
Direct Point	55.8	64.5	58.9	57.7	59.2	54.0
Lake Huron	2,022	1,373	1,187	1,613	1,703	1,827
EXTERNAL LOAD	3,211	2,756	3,492	2,813	3,260	3,263
90% C.I.	[3,014, 3,408]	[2,485, 3,027]	[3,070, 3,914]	[2,648, 2,978]	[2,987, 3,533]	[3,136, 3,390]
OUTFLOW LOSS	2,769	3,936	3,305	3,090	2,880	2,909
90% C.I.	[2,244, 3,294]	[3,383, 4,489]	[2,604, 4,006]	[2,644, 3,536]	[2,449, 3,311]	[2,427, 3,390]
IN - OUT	441	-1,180	186	-277	380	354

[a]Unmonitored diffuse load calculated with average of St. Clair and Clinton HA UALs.
[b]0% for years 1975–77, 100% for years 1978–80.
[c]Unmonitored diffuse load calculated with UAL of Belle R. within St. Clair HA.
[d]Unmonitored diffuse load calculated with UAL of Clinton HA.
[e]Unmonitored diffuse load calculated with UAL of Ruscom R. within Ruscom HA.

method assumes that instrument and measurement errors can be neglected and that instantaneous flow/concentration measurements are true representations of the tributary conditions on that day.

Dolan *et al.* (1981) evaluated 10 tributary load estimator methods and concluded that the ratio estimator method used in the present study was the most suitable for application in the Great Lakes basins. They recommended that this method be used to estimate tributary loads for total phosphorus when concentration data are limited and the daily flow record is available. The accuracy of the streamflow data used in this study was rated "fair" to "good" by the U.S. Geological Survey. "Good" means that about 95% of the reported daily discharges are within 10% of the actual values and "fair" within 15%. Chemical data represent (as much as possible) water quality conditions at the time of sampling, consistent with available sampling techniques and methods of analysis. The

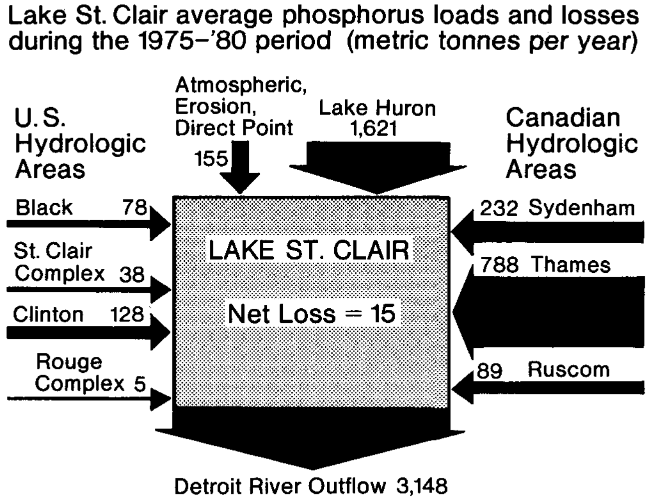

FIG. 3. Summary of Lake St. Clair average phosphorus dynamics during the 1975–80 period. Values are in MT/yr. The relative proportion of inflows and outflows are approximated by the thickness of the arrow shafts.

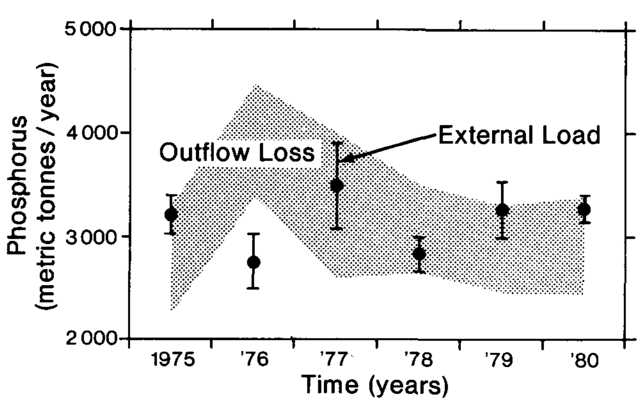

FIG. 4. Comparison of external phosphorus loads (MT/yr) to Lake St. Clair (closed circles and vertical bars represent annual loads and 90% confidence intervals) and Detroit River outflow loss (shaded region represents 90% confidence interval around annual loss) during 1975–80.

phosphorus loads from Lake Huron, estimated by Yaksich *et al.* (1982), were consistent (trends and magnitude) with other external loads to Lake Erie for seven water quality constituents during 1970–80 and are thus, for lack of better criteria, considered representative of the true Lake Huron loads. Therefore, given that 90% of the hydrologic area load was from monitored tributaries and that 95% of the total external load was from hydrologic areas and Lake Huron, we conclude that the calculated total external phosphorus loads and losses are at least a fair representation and at best an accurate estimate of the actual loads and losses to and from Lake St. Clair.

Given the nature and magnitude of possible internal sources/sinks, does the conclusion that net internal sources and sinks were negligible during the study period seem reasonable? Groundwater input of phosphorus is assumed to be insignificant compared to that entering the lake from other sources. The biological release of phosphorus from sediments and mussels to the overlying water has also been shown to be negligible (Nalepa *et al.* 1987). Assuming no resuspension, the mean Great Lakes apparent settling velocity of 14.6 m/yr (Chapra and Sonzogni 1979) and the range of Lake St. Clair mean phosphorus concentrations (14–18 μg/L) measured during eight cruises in 1975 (USEPA's STORET data base) yield a range of 227–292 MT of phosphorus potentially lost to the sediments annually. These values represent only about 7–9% of the total external load for any one year and would be lost in the variability between input and output data. In addition, given the shallowness and high wave energy of Lake St. Clair, sediment resuspension would reduce the impact of particle settling. A portion of the total phosphorus lost from the lake originates from submersed and emergent macrophytes. A maximum estimate of this amount was made by multiplying their annual production (13,780 MT submersed AFDW/yr and 60,990 MT emergent AFDW/yr; Edwards *et al.* 1988) by their average phosphorus concentration (5.9 mg P/g dry wt. submersed and 1.9 mg P/g dry wt. emergent; Hill 1979 and Mudroch 1980, respectively) and assuming an AFDW:dry wt. ratio of 0.9. The resulting value of 219 MT P/yr represents only 7% of the total outflow. Therefore, it does seem reasonable that over a 6-year period there would be no significant net source or sink of phosphorus in Lake St. Clair.

SUMMARY

The objectives of this study were twofold: 1) to estimate and present the total phosphorus budget for 1975–80, and 2) to determine whether or not the lake is a net source or sink for phosphorus. Lake Huron contributed over half (52%) of the lake's load while the seven hydrologic areas con-

tributed 43% of the remainder. About 92% of the total Canadian hydrologic area load is attributable to the Thames and Sydenham areas of Ontario. The Clinton and Black areas of Michigan were responsible for 83% of the total U.S. hydrologic area load. Were reduction of phosphorus loads to Lake St. Clair deemed desirable, control efforts might be best focused in these four hydrologic areas. Because 85% of the total hydrologic area load is from diffuse sources, a non-point source reduction plan might be most appropriate. Reduction of municipal point sources along the Clinton and Thames rivers may also be important as these sources contributed a majority of the remaining 15% of the total hydrologic area phosphorus load.

Over the 6-year study period, 1975–80, the mean external load and outflow loss of phosphorus were not found to be statistically different at the 10% level of significance. Assuming accurate estimates of the loads/losses and steady state conditions, we conclude that there was no apparent net source or sink of phosphorus in Lake St. Clair during the study period.

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